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Impact of ENSO on Cloud Distribution and Rainfall Variability in Tangerang Regency

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ABSTRACT

A type of climate variation in the Pacific Ocean known as El Niño Southern Oscillation (ENSO) is defined by an increase in sea surface temperature (SST) in the Central and Eastern equatorial areas, which affects the amount of rainfall that falls and increases. In Indonesia, the rainy season typically persists from October to March, whereas the dry season persists from April to September. Research on the influence of ENSO on rainfall has been carried out in several areas, but has not been carried out in the Tangerang area. This study aims to ascertain how the ENSO phenomena affect rainfall fluctuations and cloud distribution in the Regency of Tangerang. The secondary data, which includes information on rainfall, cloud cover, wind direction, and speed, was acquired from BMKG Meteorology Budiarto. In addition, data from the Australian Bureau of Meteorology (BOM) website's Southern Oscillation Index (SOI) was used. Surface weather analysis and Pearson correlation analysis are the data analysis techniques used. The results presented that based on surface weather study, ENSO events had an consequence on cloud distribution in Tangerang Regency. The clouds lead when the ENSO phenomenon occurs, namely Cumulus and Nimbostratus clouds with a 4-8 octa cloud cover. Meanwhile, the correlation test results show that ENSO influences seasonal and annual rainfall variations in the district of Tangerang. The largest correlation between SOI and annual rainfall occurred in 2015 with a correlation value of r-0.84 (very strong). Meanwhile, the greatest correlation between SOI and seasonal rainfall occurred in July-September with a correlation value of r=0.67 (strong).

Keywords: ENSO, cloud distribution, rainfall variations.

1. INTRODUCTION

Indonesia is an archipelagic country placed in the region's tropical climate. Two continents flank the location of Indonesia, causing winter (Monsoon). This seasonal wind causes a change in seasons in Indonesia [1]. Due to the Asian monsoon, the rainy season in Indonesia commonly happens from October to March, and its peak happens from December to February. Meanwhile, in the dry season, Indonesia happens from April to September and peaks in June until August because of the Australian Monsoon[2]. However, the climate in Indonesia only sometimes runs every year; this is influenced by many factors, one of which is a phenomenon climate in the Pacific Ocean like ENSO [3].

ENSO is a term used to define oscillations between the El Niño and La Niña stages. El Niño is the positive stage of ENSO [4]. El Niño happens when the Sea Surface Temperature (SST) in the central tropical Pacific and the East is warmer than average. Meanwhile, La Niña is the reverse of El Niño. La Niña happens when SST is in the Central and tropical Pacific Ocean. The East is more excellent than average [5]. The impact is that in most areas of Indonesia, the dry season is intense, and start of the rainy season is late when El Niño occurs. Meanwhile, in La Niña, the rainy season reaches earlier than normal. This phenomenon is usually characterized by warm pool movement in Indonesian waters to the east (central Pacific Ocean) and, simultaneously, a change in cloud origin [6].

Tangerang Regency is one of the districts in Banten province, which is precisely between 106°20′–106°43′ East Longitude and 6°00′–6°21′ South Latitude. Tengerang Regency has territorial boundaries in the north with the Java Sea, in the east with Tangerang city, South Tangerang city and Jakarta province, in the south with Lebak district and West Java province, and in the west with Serang district [7]. Tangerang Regency has an area of 959.91 km2 with most of the area being lowlands with an altitude of between 0-85 meters above sea level (masl). Tangerang Regency is located in areas with tropical climates, where the sun shines the most, and is influenced by various atmospheric events that make this area vulnerable to climate change [8].

Research on ENSO and its impact on rainfall has already done a lot. One of the research results is related to the characteristics of Indonesia's climate region based on rainfall changeability and its connection with the ENSO phenomenon. Research results indicate that rainfall in the ENSO region strongly influences Southern Indonesia [9]. Other research shows that there is a correlation between ENSO and rainfall. The strongest correlation between rainfall and ENSO is in Gorontalo (r = 0.537), whereas the weakest correlation is in Manado (r = 0.242) [10].

Indonesia has a very wide area coverage, differences in topography and geographical location affect rainfall in various regions. Therefore, the influence of ENSO for each region in Indonesia will be different. Based on the description above, there is a need for research that studies how the ENSO phenomenon influences cloud spreading and rainfall differences in Tangerang district. The research location is in Tangerang Regency, the selection of this location is based on data that there is no research regarding the impact of ENSO on the distribution of clouds and rainfall in the area.

2. METHOD

This research uses quantitative methods using a non-experimental quantitative research design. This research design was chosen because there was no intervention or treatment of the data variables [11]. The type of data in this research is subordinate data sourced from the results of a survey conducted by BMKG Budiarto station. This research was carried out in May 2023 at the Budiarto Meteorological Station which is located at the STPI Campus, Budiarto Curug Airport, Jl. Main Budiarto Airport Complex, Serdang Wetan Village, Legok District, Tangerang, Banten 15810 with geographic coordinates 06 17' 27" South Latitude 106 33' 57" East Longitude.

Research instruments used in this research are hardware and devices software. As for devices, hardware in the form of a laptop, the software used to process and analyze data, namely Microsoft Excel, SPSS, and WindRose. Materials used in this research are data obtained from BMKG Budiarto Curug Meteorological Station: rainfall data, cloud cover, direction, and wind velocity. In addition to this, the Australian Bureau of Meteorology (BOM) also used SOI value data from the website.

SOI data, rainfall, cloud cover, wind direction and speed, are processed using various software, such as: Microsoft Excel, SPSS, and WindRose. The results of data processing are used to analyze the distribution of clouds and rainfall, as well as their relationship with ENSO events. The following are the steps in processing the data:

1. Processing Wind Speed and Direction Data

   Average daily wind speed and direction in 2015 and 2020 processed with Microsoft Excel and Windrose to obtain the wind direction most dominant in the Tangerang Regency area.

2. Rainfall data processing

   Rainfall data is averaged for every three months. This data calculates the correlation coefficient between SOI values and rainfall. Correlation investigation was carried out to determine the connection between SOI values and rainfall variations. Calculation of the correlation coefficient between rainfall and SOI using SPSS software. The calculated correlation coefficient value $\left(r_{value}\right)$ is compared with the correlation coefficient in table 4 $\left(r_{table}\right)$, to find out how strong or weak the influence of SOI is on rainfall and cloud distribution. The correlation coefficient is calculated using equation 1 [4].

$$r=\frac{n\sum XY-\sum X\sum Y}{\sqrt{n\sum X^{2}-\left(\sum X\right)^{2}}\sqrt{n\sum Y^{2}-\left(\sum Y\right)^{2}}} \tag{1}$$

Where:
$X =$ Monthly average SOI value
$Y =$ Monthly rainfall at the observation post
$r =$ X and Y correlation coefficients

3. RESULT AND DISCUSSION

ENSO is a climate nonconformity in the Pacific Ocean which is considered by a rise in Sea Surface Temperature (SST) in the Central and Eastern Equatorial regions. ENSO consists of three events: Neutral ENSO, El Niño, and La Niña. ENSO phenomena can be identified based on the Southern Oscillation Index value (SOI) [12]. SOI signifies the variances in pressure between Tahiti and Darwin. SOI can indicate the expansion and the intensity of El Niño or La Niña events in the Pacific Ocean [13].

The El Niño event is indicated by a negative value due to an increase in SST in the Pacific Ocean. Meanwhile, La Niña is shown with a positive value which indicates a decrease in sea surface temperature [14]. A negative value of the SOI value indicates that the air pressure above sea level in Darwin (Australia) is higher than the air pressure above sea level in Tahiti [15]. A guide to predicting the ENSO phenomenon SOI values can be seen in Table 1 [9].

Table 1. El Niño, La Niña and Normal Estimate Guide to SOI Values

SOI value	Phenomena That Occur
Under -10	El Niño is strong
-5 to -10	El Niño is weak to moderate
-5 to +5	Normal
+5 to +10	La Niña is weak to moderate
Above 10	La Niña is strong

Based on Table 1, the SOI value obtained from the Australian BOM website between January 2012 to December 2021 shows negative and positive values varying from year to year. The highest positive value was in December 2020 with a value of 16.9, and in January 2021 with a value of 16.5, which means a strong La Niña. The highest negative value happened in April 2016 with a value of -22.0, and August 2015 with a value of -19.8, when these conditions apply, namely a strong El Niño.

Tangerang Regency is one Banten province district with a Monsoon-type rainfall pattern. The west Monsoon wind influences this pattern of sea that blows from the Java Sea [7]. The change cycle between the dry and rainy season occurs every 6 months. The rainy season starts in October and ends in March, dominated by westerly winds. The dry season starts in April and ends in September, dominated by easterly winds [16].

Monthly rainfall classification can be gotten in Table 2 based on the source Meteorology Climatology and Geophysics Council (BMKG).

Table 2. Monthly Rainfall Classification

Classification	Monthly Rainfall (mm)	Color Symbol Description
Low	0-20	1
	20-50	2
	50-100	3
Moderate	100-150	4
	150-200	5
	200-300	6
High	300-400	7
	400-500	8
Very High	>500	9

Based on rainfall data obtained from the BMKG Curug Meteorological Station, rainfall in the Tangerang Regency area for the period January 2012 to December 2021 is quite high every year, namely above 1000 mm/year [8]. The average annual rainfall for ten years is around 200 mm/year. Maximum monthly rainfall occurred in February 2020, amounting to 556 mm/month. Meanwhile, minimum monthly rainfall occurred in July 2015 and 2018, as well as in September 2019, namely 0 mm/month.

Based on data obtained from BMKG Curug Meteorological station, in August 2015, rainfall was low, namely only 10 mm/month. In addition, from June to October 2015, monthly rainfall was less than 50 mm/month, which indicates a prolonged dry season. Based on SOI value data obtained from the Australian Meteorological Agency website, the SOI value in August 2015 was highly negative, namely -19.8. From May to October 2015, the SOI value was below -10, which indicates a strong El Niño intensity. In contrast, in December 2020, the SOI value was 16.9. This means there is a strong La Niña, resulting in a long rainy season

a. Analysis of the ENSO Phenomenon Cloud Distribution

ENSO is a global phenomenon caused by ocean-atmosphere interactions, considered by an intensification in SST in the central and eastern Pacific towards the equator [17]. Under normal conditions, SST in northern and northeastern Australia is ≥ 28°C, meanwhile, in the Pacific Ocean around South America, SST is ± 20°C [18]. Small changes in the western Pacific SST pattern result in an eastward shift of seasonal sea surface winds along the equator. The wind shift is usually seen as a westerly anomaly that strengthens the increase in SST anomalies, then the wind propagates eastward to strengthen El Niño conditions. Under El Niño conditions, convection currents in the west decrease, while convection currents in the east strengthen. As convection currents in the western tropical Pacific decrease, the El Niño phenomenon results in drier conditions in Indonesia [19]. The most influential wind pattern in Indonesia is the monsoon wind. This is due to Indonesia's position between two oceans (Pacific and Indian) and two continents (Asia and Australia) [20]. Basically, seasons in Indonesia are divided into three, namely:

1. West Season

The west season/monsoon happens from October to February, when the sun is in the southern hemisphere. Therefore, the southern hemisphere (especially Australia) receives more solar heat. This results in the Australian region having high air temperatures and low (minimum) air pressure [21]. On the other hand, the Asian continent experiences low air temperatures and high (maximum) air pressure. Differences in air pressure cause winds to move from the Asian towards the Australian. Winds from Asia are deflected by the Coriolis force when crossing the equator, thus forming the west monsoon wind. This wind passes through the Indonesian Sea, carrying a lot of water vapor and causing a lot of rainfall, especially in western Indonesia [22].

2. East season

The east season/monsoon happens from April to August, where the sun shines more on the northern hemisphere. The Northern Hemisphere (especially Asia) has high air temperatures and low (minimal) air pressure [23]. The wind moves from Australia towards Asia via Indonesia. This wind does not bring moisture or rain, because it only permits over small seas and narrow straits such as the Timor Sea, Arafuru Sea, parts of southern Papua and Nusa Tenggara [24].

3. Transition Season

The transition period occurs when the sun moves around the equator, so the wind weakens and its direction is unstable. In Indonesia there are two transitional seasons, transitional season I is called the beginning of the dry season, occurring from March to April. Transition season II is called the beginning of the rainy season, occurring from September to October [25].

b. Wind Conditions in Tangerang Regency

A graph of wind direction and speed produced by surface weather data when the El Niño event occurred in July 2015 can be gotten in Figure 1.

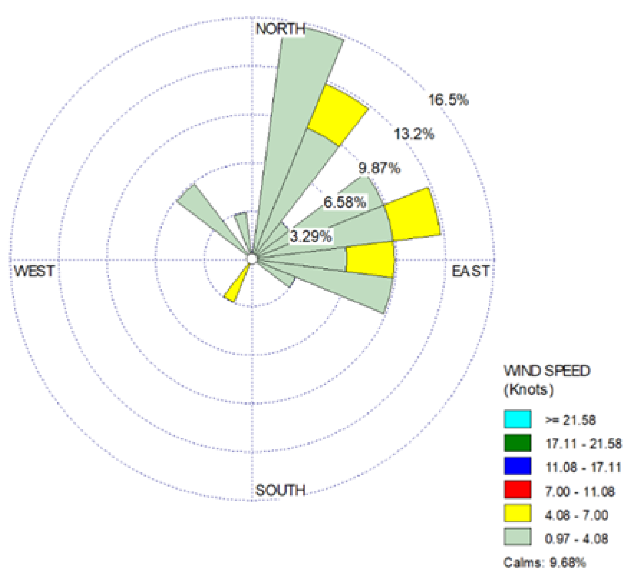

Figure 1. Graph of Wind Direction and Speed in July 2015

Based on the wind direction data in Figure 1, the wind direction mostly blows from the east with a maximum speed of up to 7 knots (3.6 m/s). The wind speed that occurred in July 2015 was between 1-4 knots and 4-7 knots, with a calm wind percentage of 9.68%. The dominance of winds from the east causes the dry season to occur in the Tangerang Regency. SOI data in July 2015 was negative (-), indicating that sea level pressure (SLP) in Darwin was higher than normal. Meanwhile, Tahiti has a lower SLP than usual. This supports the accumulation of warm pools around Tahiti or the central Pacific.

La Niña occurred in 2020-2021, the rainy season in Tangerang Regency increased significantly. Figure 2 shows a graph of wind direction and speed produced from surface weather data during the La Niña event in December 2020.

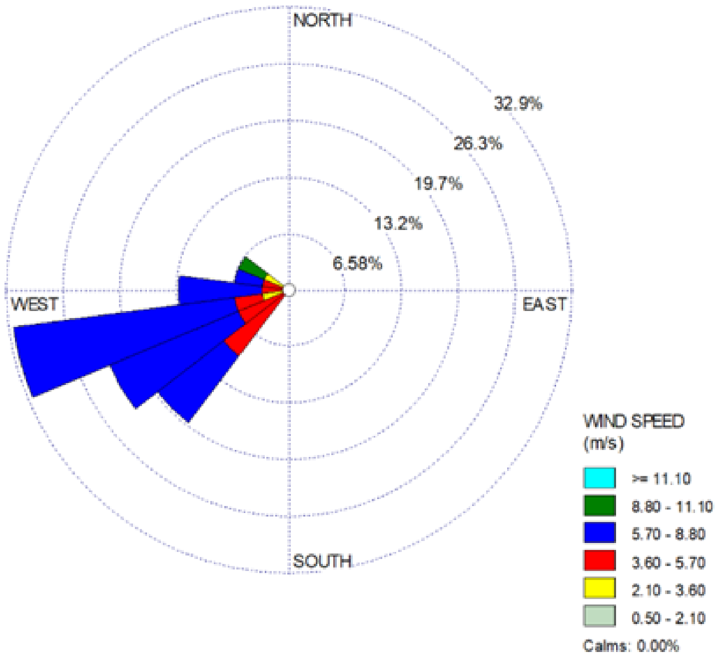

Figure 2. Graph of Wind Direction and Speed in December 2020

Based on the wind direction data in Figure 2, the wind direction mostly blows from the west with a maximum speed of up to 8,8 knots (45,3 m/s). The wind speed that occurred in December 2020 was between 3,6-5,7 knots and 5,7-8,8 knots, with a calm wind percentage of 0,00%. In December 2020, west winds dominated. This wind brings slightly moist air masses from the Pacific, Indian Ocean and South China Sea which results in a lot of rainfall [26]. Table 3 shows cloud cover data in Tangerang Regency in July 2015 and December 2020.

Table 3. Cloud data for July 2015 and December 2020

	h	Nh	Cl	Cm	Ch
December 2020	545	4	5	8/2	2/2
July 2020	600	3	5	2/1	2/1

Information:
h = cloud base height (m)
Nh = Low Cloud Cover (octa)
Cl = Low Cloud Type (octa)
Cm = Medium cloud type/cover medium cloud (octa)
Ch = High cloud type/cloud cover high (octa)

Based on data obtained from BMKG Curug, in December 2020, the atmosphere in the Tangerang area was dominated by Nimbrostratus, Cumulus and Cirocumulus clouds with cloud cover of 4-8 Okta with a height of 545 meters. This is in line with the outcomes of research shown by Ismiati (2022), which shows that El Niño results in the construction of cumulus clouds which can surge rainfall in the Tangerang area [27]. Meanwhile, in July 2015, the clouds that dominated Tangerang's atmosphere were Nimbrostratus and Cirostratus clouds with cloud cover of 3-5 Octa at a height of 600 meters.

In general, cloud cover in Tangerang Regency is dominated by low clouds. In the dry season, clouds tend to spread evenly. In the rainy season, clouds tend to gather to form a dome that covers the sky. Cloud cover in the dry season is more homogeneous. Cloud cover during the rainy season consists of low clouds and medium clouds which dominate more than high clouds. Meanwhile, in the dry season low clouds dominate and few high clouds are found.

c. Analysis of the ENSO Phenomenon on Rainfall Variations

Graph of SOI values and annual rainfall in the Tangerang Regency for 2012-2021 can be gotten in Figure 3.

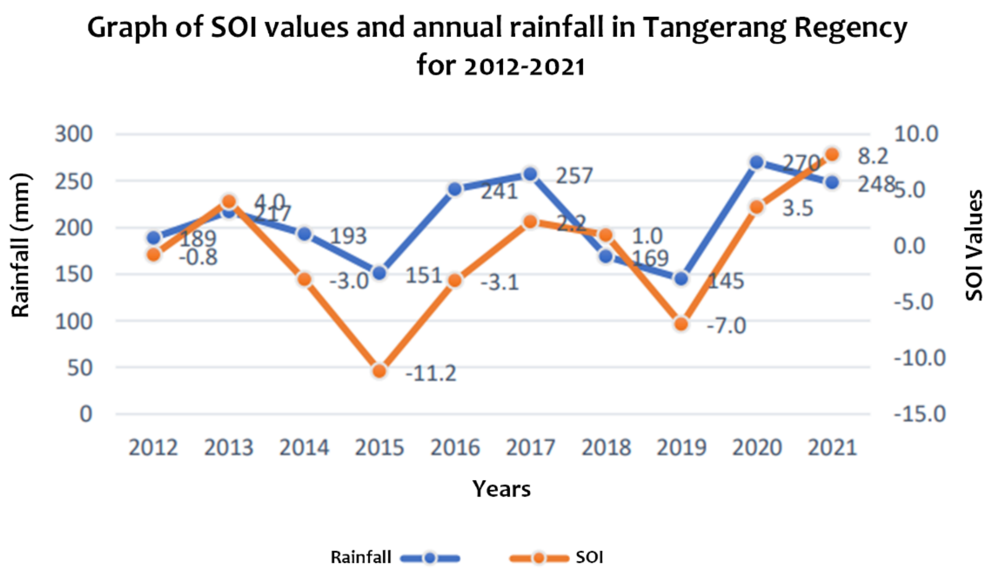

Figure 3. Graph of SOI Values and Annual Rainfall in Tangerang Regency for 2012-2021

Based on Figure 3, it can be seen that there is a positive connection between SOI values and annual rainfall. Rainfall changes every year. From this graph, it can be gotten that when the El Niño phenomenon occurred in 2015, rainfall decreased significantly, namely 151 mm, with a SOI index of -11.2, which means a strong El Niño. In 2021, when a La Niña event occurs, rainfall increases by 248, with a SOI index of +8.2 which indicates moderate La Niña.

The graph of SOI values and seasonal rainfall in Tangerang Regency in 2012-2021 can be seen in Figure 4

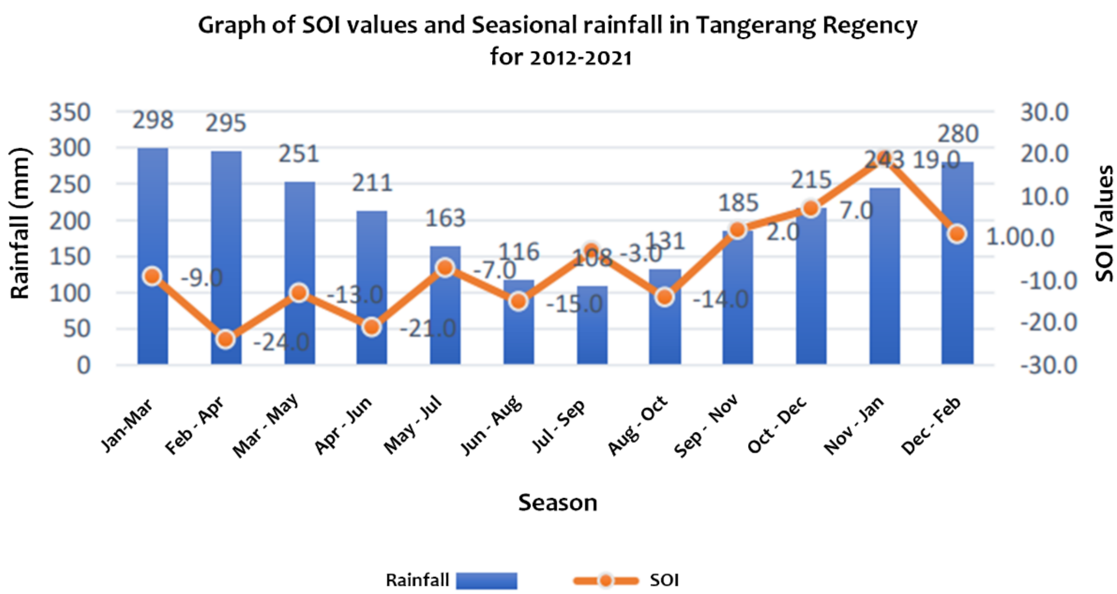

Figure 4 Graph of SOI Values and Seasonal Rainfall in Tangerang Regency in 2012-2021

Based on Figure 4, seasonal rainfall and SOI values in Tangerang Regency is fluctuating. In certain seasons (for example July-September), there is a positive correlation between SOI and rainfall. When the SOI value is small (-15), then rainfall decreases, only 108/mm. Apart from that, there is also a negative correlation between SOI values and rainfall, for example in February-April, where the SOI value was -24, while rainfall was 295/mm. To find out the connection between ENSO and rainfall, it is necessary to test the correlation between SOI values and rainfall in Tangerang Regency, then compare the r table values. Classification of correlation values is presented in Table 4 [11].

Table 4 Classification of Correlation Values

r-value (correlation)	Information
± (0,000 – 0,199)	Very weak
± (0,200 – 0,399)	Weak
± (0,400 – 0,599)	Strong enough
± (0,600 – 0,799)	Strong
± (0,800 – 1,000)	Very Strong

The Pearson correlation method produces a correlation from -1 to 1. The greater the value of the coefficient of the correlation, the greater the relationship between variables [12]. In the correlation coefficient, a negative value shows a relationship contrarywise proportional between parameters, while a positive value shows a directly proportional relationship.

Table 5 Correlation of SOI Values with Annual Rainfall in Tangerang Regency

Year	Correlation	Level of significance
2012	0.627	0.029
2013	0.684	0.014
2014	0.580	0.048
2015	0.840	0.001
2016	-0.456	0.137
2017	0.649	0.015
2018	0.448	0.144
2019	0.110	0.733
2020	0.680	0.015
2021	0.718	0.009

Table 5 shows the correlation between SOI values and annual rainfall in Tangerang Regency is different, the correlation between SOI and rainfall can be positive and negative. In general, from 2012-2021, there is a fairly strong to very strong correlation between SOI and rainfall values. There was a negative correlation in 2016. The strongest correlation between SOI values and rainfall in Tangerang Regency occurred in 2015, with a correlation value of r=0.84, a significance level of 0.001. As can be seen in Figure 3, in 2015 SOI was negative (-11.2), so there was a large decrease in annual rainfall, only 193/mm. In 2016, the correlation between SOI and rainfall was negative. As can be seen in Figure 2, when the SOI value is -3.1, the rainfall is actually high, namely 241/mm. This shows that there are other factors that influence rainfall besides SOI, such as: wind patterns, water levels, and others [28]. Meanwhile in 2020, the correlation value between rainfall and SOI was 0.68 (strong), with a significance of 0.0015. as seen in Figure 3, when SOI is positive 3.50, rainfall in Tangerang Regency is quite high, amounting to 270/mm.

The results of the correlation between seasonal rainfall and seasonal SOI values can be seen in Table 6. The correlation between SOI and seasonal rainfall fluctuates, from very weak correlation to strong correlation. There is also a negative correlation between SOI and seasonal rainfall, namely from February to April, and March to May. A strong correlation between SOI and rainfall occurs in July to September, with a correlation of 0.699 (strong), and in August to October with a correlation of 0.616 (strong). The correlation between SOI and seasonal rainfall is in the quite strong category (0.400 – 0.599) occurring in several seasons, such as: May to July, June to August, September to November, and November to January. Meanwhile, the correlation between SOI and seasonal rainfall is in the weak category (0.200 – 0.399) occurring in two seasons, namely: October to December, and December to February. Correlation in the very weak category (0.000 – 0.199) also occurs in two seasons, namely: January to March, and April to June. A strong correlation between seasonal rainfall and the ENSO phenomenon occurs during the dry season and seasonal transitions, from the dry season to the rainy season. Negative correlation (February to April and March to May) indicates that when there is an intensification in SST in the eastern Pacific Ocean (El Niño), it results in a reduction in the amount of rainfall in the transition season, wet monsoon to dry monsoon.

Table 6 Correlation of SOI Values with Seasonal Rainfall in Tangerang Regency in 2012-2021

Month	Correlation	Level of significance
January – March	0.099	0.600
February – April	-0.137	0.472
March – May	-0.183	0.335
April – June	0.105	0.580
May – July	0.438	0.021
June - August	0.522	0.001
July – September	0.669	0.002
August – October	0.616	0.001
September – November	0.453	0.014
October – December	0.353	0.063
November – January	0.403	0.025
December – February	0.393	0.052

In general, rainfall changeability in Indonesia is prejudiced by the Asian monsoon and the Australian monsoon. The El Niño Southern Oscillation (ENSO) phenomenon reasons changes at the beginning of the season and between seasons. Apart from that, cloud formation and rainfall in Indonesia are also influenced by local conditions, such as changes in topography and wind direction. Atmospheric dynamics in the tropics are very sensitive to distinctions in sea surface temperature, so that variations in sea surface temperature (SST) are considered a reliable tool for predicting seasonal climate changes, especially in regions where the forcing relationship is quite strong [29].

The geographical location of Tangerang Regency is not directly open to the Indian Ocean and Pacific Ocean. In this geographical location, the influence of the monsoon is stronger than the Pacific and Indian Ocean phenomena. Positive/negative Pacific sea surface temperature (ENSO) anomalies correlate with decreased/increased seasonal and annual precipitation. The observed correlations were weak to strong. The decrease/increase in seasonal and annual rainfall in Tangerang Regency is positively/negatively correlated with sea surface temperature anomalies in the Pacific (ENSO phenomenon) [30].

In 2015, the El Niño phenomenon caused the dry season to arrive earlier and with a longer duration [31]. On the other hand, during El Niño, rainfall in Tangerang Regency is slightly higher than normal, and lasts for a longer duration, so it can cause flooding. This event shows the strong influence of climate phenomena from the Pacific Ocean and monsoon winds on rainfall in Tangerang Regency.

4. CONCLUSION

The research results show that ENSO influences cloud formation in Tangerang Regency. When El Niño occurs, cloud cover is dominated by low clouds, whereas during La Niña, cloud cover is conquered by low clouds and medium clouds. Based on the results of the Pearson Correlation test, it was found that ENSO has a significant influence on annual rainfall and seasonal rainfall in Tangerang Regency.

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